Yield components of high-yielding Australian cotton cultivars

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Abstract. Cotton (*Gossypium hirsutum*) yield can be broken down into components that make up total lint yield, namely bolls/m^2 (fruiting sites and boll retention) and lint/boll (seeds/boll and lint/seed). Lint yields of Australian cultivars during the last 30 years have increased by 1.8% per year and the aim of this study was to determine which yield components had contributed to that progress. Six cultivars were used, two released during the 1970s (DP 16 and Namcala), two from the mid 1990s (Sicala 40 and Sicot 189), and two from the early 2000s (Sicot 71 and Sicot 71B - the latter being a Bollgard II® cultivar). These cultivars were grown in replicated field experiments at three locations selected to represent different cotton growing environments in Australia; Boggabilla (warmer), the Australian Cotton Research Institute at Narrabri (medium) and Carroll (cooler). At maturity bolls were harvested and the various yield components analysed. Across sites and cultivars, yield was most correlated with bolls/m^2 (r=0.69***), then with lint/seed (r=0.44***) and also with boll retention (r=0.25*). There was a negative linear relationship between boll retention and fruiting sites/m^2, and boll retention and seeds/boll. Lint/seed was a relatively stable trait and was not negatively related to boll retention. We conclude that yield increases have come from increased bolls/m^2 and from selection for high lint percentage (lint yield divided by seed cotton yield) which has increased lint per seed. This study will assist breeders to focus selection pressure on further improving yield of Australian cultivars.

Keywords/phrases: cotton, *Gossypium hirsutum*, yield components, yield, retention, fruit development, lint/seed

Introduction

Australia holds the record of the world's highest average yield at 1779 kg/ha, of all the countries that produce in excess of 45 million kg of cotton per year. The yield of any crop can be broken down into its components to determine how yield is attained. To facilitate breeding for high yields, it is logical to examine the various components individually. This way, the components having the greatest influence on yield, in both a positive and negative manner, can be identified (Kambal 1969; Sharma and Singh 1999). The components are influenced by genetic and environmental variation and by the interaction between these two (Worley *et al.* 1974). The primary lint yield components that contribute to lint yield are bolls per unit area, seeds/boll and lint/seed (Manning 1956; Kerr 1966; Worley *et al.* 1974; Wilson *et al.* 1994). The most commonly used yield component equation for cotton is the geometric identity proposed by Kerr (1966):

Yield = bolls/unit area **x** seeds/boll **x** lint/seed (1)

Heitholt (1999) proposed the equation:

Yield = bolls/unit area **x** lint/boll (2)

Equation (2) is similar to Kerr's equation, since seeds/boll and lint/seed are the key contributors to lint/boll. Fruiting sites and fruit retention are the components determining boll numbers. The aim of this study was to determine which yield components had contributed to yield progress in modern Australian cotton cultivars. More information is needed on how yield components have changed over time, and environmental influences on Australian cultivars. By knowing what yield components have changed, the key yield components can be targeted in specific environments to continue Australia's breeding efforts.

Materials and methods

Treatments

Six cotton (*Gossypium hirsutum*) cultivars were grown in three locations chosen to give a range of environmental conditions across the cotton growing region of northern NSW over the 2004/2005 season. "Korolea" at Boggabilla (28° S, 150° E), near Goondiwindi represents a hotter cotton growing region, Australian Cotton Research Institute (ACRI), Myall Vale (30° S, 151° E), 30 km west of Narrabri represents a moderate region and "Long Acres" at Carroll (31° S, 150° E), the Breeza plains south of Gunnedah represents a cooler region. The six cultivars were chosen to represent a progression of cotton cultivars grown in Australian from the 1970s to current. DP 16 and Namcala were grown in the early 1970s and used as reference cultivars, Sicala 40 and Sicot 189 were released in the early 1990s and Sicot 71 and Sicot 71B in the early 2000s. Sicot 71B is a genetically modified Bollgard II® cultivar that contains both *Cry1Ac* and *CryAb* genes of the *Bacillus thuringiensis* (Bt) bacterium from Monsanto. The cultivars were planted in a randomised block design with four replicates at each location. In each replicate, there were three 13 m rows of each cultivar. All sites used in this study were managed to ensure non-limiting nutrient and water conditions. Weeds and insects were monitored and controlled as required.

Data collection

To calculate fruit retention, the number of fruit retained to maturity was divided by the total number of fruiting sites at maturity. The yield component measurements were carried out at maturity. Boll number, plant density, fruiting sites, seed cotton weight, gin turnout (weight ratio of lint to seed cotton), seed weight and handpicked lint were measured on the same 1 m row of plants that were used for plant mapping. Seed cotton weight is the weight of seed with cotton fibres still attached and gin turnout is the ratio of cotton lint to seed cotton. To obtain turnout, the cotton was ginned in a small gin. The multiplicative yield component equation used for this study was adapted from Heitholt's equation, yield = bolls/m^2 **x** lint/boll equation (Kerr 1966; Heitholt 1999)and further expanded to: Yield = fruiting sites/m^2 x boll retention x seeds/boll x lint/seed.

Data analysis

Final yield and the various yield components were analysed by Residual Maximum Likelihood (REML) analysis in Genstat v13. Boll retention at maturity and fruit retention were analysed using binomial logistic regression and analysis of deviance.

Results

There was no cultivar by location interaction in any of the yield components measured. Hence, only the significantly (P<0.05) different cultivar main effects are presented. The reference cultivars, DP 16 and Namcala had the lowest yields (Table 1). The most recent cultivars, Sicot 71 (303 g/m^2) and 71B (297 g/m^2) had similar yields to Sicala 40 (308 g/m^2). Sicala 40 (104 bolls) produced higher (P<0.05) bolls/m^2 than both reference cultivars (82 and 89 bolls) (Table 1). Sicot 71B (120 bolls) produced more (P<0.05) bolls/m^2 than all conventional cultivars used, including Sicot 71 (95 bolls). There was no difference (P>0.05) in the number of fruiting sites/m^2. Namcala (0.22) had lower (P<0.05) and Sicot 71B (0.38) had higher (P<0.05) boll retention than all conventional cultivars tested.

Lint/boll was lowest for Sicot 71B (2.5 g), DP 16 and Namcala (Table 1) and highest for Sicot 71 (3.3 g) (P<0.05) in this study. Sicala 40 (3.0 g) and Sicot 189 (2.9 g) had higher lint/boll (P<0.05) than Namcala (2.7 g). There was no consistent trend in seeds/boll among the conventional cultivars (Table 1). Sicot 71B had the lowest (P<0.05) number of seeds/boll (28 seeds). The increase in lint/boll was mainly due to the increase in lint/seed (Table 1). The modern cultivars, Sicala 40 (0.096 g) and Sicot 71 (0.095 g) had 20% more lint/seed compared with the reference cultivar average (0.079 g). Lint/seed for Sicot 71B (0.088 g) was higher (P<0.05) than DP 16 (0.078 g), Namcala (0.080 g) and Sicot 189 (0.078 g), but lower (P<0.05) than both Sicala 40 and Sicot 71.

Location had no impact on lint yields (P=0.281, data not presented). The cooler location at Carroll had more (P<0.05) fruiting sites/m^2 (414) and lint/boll (3.17 g), but lower (P<0.05) boll retention (0.24). Both the warmer locations at Myall Vale (103 bolls) and Boggabilla (98 bolls) had higher bolls/m^2 due to higher boll retention, but lint/boll was lower (P<0.05). There was a negative relationship between fruiting sites and boll retention rate, and between seeds/boll and boll retention rate between sites and across genotypes. As the number of fruiting sites/m^2 increased, boll retention decreased (y=-838x+603, r=0.83, P<0.01). The negative relationship between boll retention and the number of fruiting sites was possibly due to competition for assimilates which is finite in supply and must be partitioned between the various sinks (Constable 1991; Pettigrew 1994). As boll retention rates increased, the number of seeds/boll decreased (y =-33x +43, r=0.55, P<0.01). Lint/boll increased with an increase in seeds/boll (y=0.7+0.6, r=0.84, P<0.001). Across sites and cultivars, lint yield (g/m^2) was most strongly correlated with bolls/m^2 (y=2x+75, r=0.69, P<0.001), then with lint/seed (y=2631x+45, r=0.44, P<0.001) and also with boll retention (y=1.43x+226, r=0.25, P<0.05). The strong influence of bolls/m^2 is in agreement with Worley *et al.* (2004). Lint/seed appears to be a relatively stable trait as it is correlated with lint yield, but not correlated to boll retention. Greater lint/seed can occur through production of more fibres per seed (Bednarz *et al.* 2007).

Table 1. Mean lint yield (g/m^2), bolls/m^2, fruiting sites/m^2, boll retention, lint/boll (g), seeds/boll and lint/seed (g) at maturity for six cultivars (Namcala, DP16, Sicala 40, Sicot 189, Sicot 71 and Sicot 71B) averaged across three locations (Boggabilla, Myall Vale and Carroll). Means followed by the same letter within the column are not significantly different at *P*=0.05. The l.s.d. values are at *P*=0.05, using Fisher's protected l.s.d. tests for the cultivar main effect. Boll retention was analysed by binomial logistic regression and analysis of deviance. N.s. – Not significantly significant at *P*=0.05.

Cultivar	Yield (g/m^2)	Bolls/m^2	Sites/m^2	Boll retention	Lint/boll (g)	Seeds/boll	Lint/seed (g)
Namcala	209.2a	82a	380	0.22a	2.63a	33.2ab	0.080a
DP 16	236.8ab	89ab	310	0.29b	2.71ab	35.0bc	0.078a
Sicot 189	266.7b	94abc	344	0.27b	2.88b	36.7c	0.078a
Sicala 40	308.4c	104c	375	0.28b	2.96b	31.8a	0.096c
Sicot 71	302.9bc	95abc	322	0.28b	3.25c	34.3bc	0.095c
Sicot 71B	296.7bc	120d	317	0.38c	2.47a	28.2a	0.088b
l.s.d.	41.24	13	n.s.	-	0.25	3.15	0.0033

Australian cotton breeders have been successful in improving cotton lint yields in cultivars released since the early 1970s (Constable *et al.* 2001). The increase in lint/boll over time in Australian cultivars appears to be primarily due to the increase in lint/seed. From 1983-1998, Australian cotton cultivars released by CSIRO Plant Industry have increased an average of 12.9 kg lint/ha/year, representing a 1.8% yield increase per year (Constable *et al.* 2001). However, American cultivars showed a steadily decreasing rate of improvement from the mid 1980s to 1992, when the rate of yield gain approached zero and then cultivar yields decreased at a rate of approximately 20 kg lint/ha/year in 1998 (Lewis *et al.* 2000). In America, DP 16 produced approximately 0.072 g lint/seed, a value similar to the 0.078 g lint/seed in our study. Cultivars from the mid to late 1990s, DP 50 and Suregrow 125 produced only 0.06 g lint/seed (Lewis *et al.* 2000). There was a decrease in lint/seed and an increase in seeds/boll produced in American cultivars of the mid 1990s (Lewis *et al.* 2000) while in Australia, seeds/boll have remained relatively constant and lint/boll has been increasing, mainly due to an increase in lint/seed. If a cultivar depends heavily on a high number of seeds/boll to obtain an acceptable yield, the plant must fix a higher amount of carbon to achieve this result. In terms of energy requirement, the cotton plant must fix nearly twice as much carbon to produce a kg of seed compared with a kg of lint (cellulose) (West and Todd 1956) since cotton seed contains approximately 20% triglyceride, or oil (Lewis *et al.* 2000). A negative relationship was also found between lint yield and seed oil percentage (Mert *et al.* 2005). Lewis *et al.* (2000) proposed that by selecting for high seeds/boll (Harrell and Culp 1976), lint yields can become more variable and less reliable.

Conclusions

The data in this study showed a negative linear relationship between boll retention and seeds/boll, and between boll retention and fruiting sites/m^2. The information gained from this study will help cotton breeders to target specific yield components such as larger bolls (lint/boll) and lint/seed by selecting for high gin turnout (lint percentage).

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